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Barriers and drivers for biking: What can policymakers learn from social media analytics?

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ABSTRACT

Broader acceptance of biking as a means of urban transportation is essential for reducing the externalities of motorized transport and contributing to individual health. This paper explored the barriers and drivers for biking from citizens' perspectives and aimed to provide policy suggestions to promote cycling. Social media analytics was applied supported by topic modeling, machine learning, and sentiment analysis. Topic modeling was used to assign social media messages to the relevant dimension, while sentiment analysis was employed to measure citizens' satisfaction levels. The study was conducted in Turkey and covers more than 600,000 tweets posted between 2016 and 2021. The results revealed that social media analytics generated compatible results with surveys and interviews and successfully defined the factors that affect cycling. Moreover, it captured the temporal changes and provided a dynamic view of policymaking. Findings pointed to the importance of economic conditions, physical infrastructure, and safety&security among barriers and elaborated health, entertainment, and socialization among drivers. The proposed new approach was compared with the traditional methods and its advantages and disadvantages were discussed. Policy implications were derived.

1. Introduction

The shift from motorized transport to active forms of travel (i.e., walking, scooting, biking) reduces the externalities of motor vehicles (i.e., air pollution, congestion, noise), provides cost efficiency, and contributes to personal health (Daley et al., 2007; Nkurunziza et al., 2012; Blitz, 2021). However, structural, social, environmental, economic, and personal obstacles can prevent or slow down this shift. These obstacles must be well defined and eliminated to promote active forms of travel. Also, the sources to motivate citizens to active transport should be well understood, and encouraging policies should be adopted. Thus, the precise definition of drivers and barriers is of great importance in establishing effective policies to promote active travel.

Many studies have been previously carried out on barriers and enablers for biking using surveys and interviews (Nkurunziza et al., 2012; Winters et al., 2015; Iwińska et al., 2018; Félix et al., 2019; Sabyrbekov and Overland, 2020; Shaaban, 2020; Blitz, 2021). Traditional methods effectively reveal the drivers and barriers at a particular time, but they are insufficient in explaining the temporal changes. However, these factors change over time, and monitoring these changes is necessary to understand the dynamics behind cycling behavior (Shaaban, 2020) and promote and maintain sustainable lifestyle practices (Axon, 2017). Examining temporal changes

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also allows monitoring the impact of policies implemented in the past and can provide directions for future policies. In traditional methods, however, it is not easy to measure the retrospective factors that affect individuals' cycling preferences (Félix et al., 2019). At this point, individuals' past social media posts and user-generated content offer a rich resource for capturing temporal changes. Twitter's time-stamp tweets have been widely used in literature to understand temporal variations in transport dynamics (Hosseini et al., 2018; El-Diraby et al., 2019; Osorio-Arjona et al., 2021).

This being the case, the current paper aims to monitor the temporal changes in factors affecting cycling decisions and provide a dynamic view of policymaking using a social media analytics framework. The proposed approach is supported by topic modeling, machine learning, and sentiment analysis. Social media analytics has been used effectively in transport policies in recent years (Gal-Tzur et al., 2014; Grant-Muller et al., 2015; Nisar and Prabhakar, 2018; Mogaji and Erkan, 2019; El-Diraby et al., 2019) and its results have been compared with traditional methods (Casas and Delmelle, 2017). To the best of our knowledge, this study applies social media analytics to define the factors affecting biking for the first time. Tweets gathered from 2016 to 2021 were assigned to the relevant dimension by topic modeling. Sentiment analysis was used to determine how much citizens complain about each barrier and how satisfied they are with each driver. Thus, the factors that prevent and encourage cycling were identified and temporal changes were investigated.

Another contribution of the study to the literature is the width of the geographical region and the large number of participants covered. Heinen et al. (2010) noted that most studies in the literature included only a limited number of participants due to the low regional cycling rates, and the results may change with the increasing number of participants. Social media analytics can cover a wider region more quickly and easily than traditional methods and allows for reaching a larger population, including those unwilling or unable to participate in surveys and interviews (Casas and Delmelle, 2017; Howard, 2020). This study analyzed more than 600,000 tweets across Turkey and gave the opportunity to compare the findings with the existing literature.

From the practice point of view, this study explores the factors affecting cycling as a mode of active travel in Turkey. In the last ten years, many government-supported projects have been developed to popularize bicycles in Turkey. These projects are also supported by the European Union and include the development of bicycle path master and implementation plans, providing financial support for urban bicycle path projects, encouraging cycling as a mode of urban transport, and transferring European know-how to Turkey (WRI Turkey, 2020). Legal regulations are also coming into force that would promote biking. The infrastructure investments have started to increase with the "Design and Construction of Bicycle Paths, Bicycle Stations and Bicycle Parks on Urban Roads" regulation issued by the Ministry of Environment and Urbanization in 2015 (Çevre ve Şehircilik Bakanlığı, 2015). Moreover, a new regulation in 2019 mandated the construction of bicycle paths in the zoning plans of newly built regions (Çevre ve Şehircilik Bakanlığı, 2019). All these developments show that increasing the rate of biking in urban transportation has been adopted as a state policy. Several studies were conducted in the national literature examining the factors affecting cycling in a limited geography (Kalaycı et al., 2015; Koçak, 2016; Balcı et al., 2018; Öztürk and Çoruh, 2019; Karagöz and Erdem, 2019; Yıldız and Bektaş, 2021), but a study exploring the impact of current policies across the country is lacking. This research will reveal the success of the current policy in eliminating concerns about cycling and encouraging citizens to bike. Moreover, by determining the factors affecting cycling from a citizen perspective, this paper aims to provide policy suggestions to decision-makers to promote biking in Turkey.

The rest of the paper is organized as follows. Section 2 presents a comprehensive literature review of the barriers and drivers that affect the cycling decision. Section 3 details the methodology, and Section 4 presents the findings. Section 5 discusses the findings and Section 6 offers a conclusion and policy suggestions.

2. Literature review

Due to its importance in policymaking, the factors affecting cycling behavior have been widely discussed in the literature. The consensus is that a supportive built environment is critical in promoting biking (Aldred et al., 2017). Physical infrastructure, including segregated cycle paths, connections, facilities, signals at intersections, etc., is the most important component of the built environment. Many empirical studies have found that a new-built and well-designed physical infrastructure encourages citizens to cycle and significantly increases biking rates (Marqués et al., 2015; Panter et al., 2016; Félix et al., 2020). On the other hand, poor infrastructure was revealed to be an important obstacle to cycling (Daley et al., 2007; Handy et al., 2010; Félix et al., 2019; Shaaban, 2020).

Infrastructure not only makes biking possible but also supports active transport by making cyclists feel safe. The literature shows that safety concerns, including fear of injury, lack of safety, theft, vandalism, real and perceived danger are one of the biggest obstacles to cycling (Daley et al., 2007; Dill and Voros, 2007; Heinen et al., 2011; Götschi et al., 2016; Manaugh et al., 2017; Hopkins and Mandic, 2017; Iwińska et al., 2018; Blitz, 2021; Boufous et al., 2021). Many studies have also recorded that high traffic speed and motorized traffic volume increase cyclists' and pedestrians' safety concerns (Rahman et al., 2022; Boufous et al., 2021; Musselwhite, 2021; Grudgings et al., 2021). Moreover, parents with a low perception of safety prevent their children from cycling (Cole et al., 2010; Clayton and Musselwhite, 2013). Security concerns have been largely associated with infrastructural weakness (Daley et al., 2007; Blitz, 2021). The lack of suitable infrastructure forces cyclists to use automobile and pedestrian paths, which raises safety concerns and causes cycling to be perceived as dangerous (Fishman et al., 2012; Clayton and Musselwhite, 2013). As Musselwhite (2021) reports, sharing the pavements with cyclists narrows the space for pedestrians and poses a safety risk and creates a barrier for pedestrians. Separate lanes, signalization of intersections, and other safety precautions make cyclists feel safe and create legitimacy for modal choice (Daley et al., 2007; Bonham and Wilson, 2012; Clayton and Musselwhite, 2013; Damant-Sirois and El-Geneidy, 2015; Verma et al., 2016). Therefore, the improvement in the perception of safety positively affects the choice of bicycle (Akar et al., 2013; Macmillan and Woodcock, 2017).

A well-built infrastructure also promotes recreational cycling. The funny, exciting, greenery, and challenging aspects of cycling

increase users' intrinsic satisfaction (Daley et al., 2007; Daley and Rissel, 2011; Blitz, 2021). Clayton and Musselwhite (2013) found that safe and playful cycling routes support recreational biking activities by encouraging parents to cycle with their children and benefit from kinaesthetic aspects.

In addition to the built environment, personal characteristics such as age, gender, skills, knowledge, and experiences are also very important in travel mode choice. Gender affects both the perception of security and the purpose of use. Akar et al. (2013) and Blitz (2021) recorded different perceptions of men and women towards biking safety, where women feel more unsafe while cycling. Due to the high safety concern, female riders feel safer when cycling with others (Daley et al., 2007). Similar safety issues also affect women's cycling purposes. While women are less likely to commute by bike, they are more likely to participate in recreational activities (Damant-Sirois and El-Geneidy, 2015). Age also influences cycling preferences, where younger adults have a more positive attitude towards cycling (Dill and Voros, 2007; Handy et al., 2010; Castillo-Manzano and Sanchez-Braza, 2013; Blitz, 2021). A systematic literature review by Aldred et al. (2017) concluded that female and older cyclists strongly preferred bike infrastructure separated from motor traffic. Riding and maintenance skills (Daley et al., 2007; Hopkins and Mandic, 2017), knowledge about safe and practical routes (Daley et al., 2007; Clayton and Musselwhite, 2013); time flexibility of the job (Castillo-Manzano and Sanchez-Braza, 2013), concern with health and physical fitness (Daley et al., 2007; Handy et al., 2010; Félix et al., 2019); previous cycling experiences, habits, and past behaviors (Heinen et al., 2010; Hopkins and Mandic, 2017; Sulikova and Brand, 2021) also affect the cycling decision.

Many studies have drawn attention to the decisive influence of socio-cultural values and attitudes on cycling decisions (Daley et al., 2007; Heinen et al., 2010; Bonham and Wilson, 2012; Willis et al., 2015). Embedded car culture in society, people's indifference to active transport options, and negative attitudes towards cyclists have been reported as important obstacles to cycling (Cole et al., 2010; Wang et al., 2015). In such a social environment, where cycling is not widely accepted, cyclists may feel under pressure because they slow down the traffic (Daley et al., 2007; Daley and Rissel, 2011). On the contrary, a supportive social environment and positive social norms motivate citizens to cycle. Cycling is an important activity for getting together with friends and family members and improving social relationships (Daley et al., 2007; Iwińska et al., 2018; Boufous et al., 2021). The number of cyclists in a community has a reinforcing effect, where increasing the number of cyclists in a neighborhood makes cycling more attractive and acceptable (Wang et al., 2015). Thus, Damant-Sirois and El-Geneidy (2015) defined social policies as effective tools to improve the cycling image in society and promote biking.

Health benefits, including mental, physical, and emotional well-being, encourage people to cycle (Daley et al., 2007; Götschi et al., 2016; Iwińska et al., 2018; Boufous et al., 2021). Environmental awareness and the desire to reduce the negative externalities of motorized transport positively affect sustainable and active transport preferences (Dill and Voros, 2007; Verma et al., 2016; Flores and Jansson, 2021; Blitz, 2021; Boufous et al., 2021). Macmillan and Woodcock (2017) defined a reinforcing relationship between cycling and sustainable transport policies, where a growing number of cyclists force the political will to implement environmentalist policies. Here, Damant-Sirois and El-Geneidy (2015) emphasized the importance of cycling purposes and revealed that health and environmental motivations affect the transport choice in recreational cycling but not in commuting.

Practical advantages or disadvantages compared to motorized transport are also decisive in cycling decisions. Previous studies have revealed a negative relationship between commuting distance and cycling; that is, people prefer motorized transportation rather than cycling as the distance increases (Dill and Voros, 2007; Daley et al., 2007; Handy et al., 2010; Heinen et al., 2010; Heinen et al., 2011; Bonham and Wilson, 2012; Akar et al., 2013; Marqués et al., 2015; Blitz, 2021). For leisure cyclists, however, distance is losing its importance (Damant-Sirois and El-Geneidy, 2015). Connectivity is also a determinant of the practicality of biking, where proximity to cycle paths and other infrastructures support the cycling preference (Dill and Voros, 2007; Wang et al., 2015). Fishman et al. (2012) stated that the long sign-up process and mandatory helmet legislation in bikesharing systems weaken the practicality and reduce the usage rates.

Cost-efficiency of biking has been defined as an essential motivator in the literature (Dill and Voros, 2007; Daley et al., 2007; Heinen et al., 2010; Iwińska et al., 2018). Akar et al. (2013) found that the increases in gas prices and travel costs strengthen the possibility of cycling. Those who bike for commuting are more sensitive to cost-efficiency (Damant-Sirois and El-Geneidy, 2015; Daley and Rissel, 2011). On the other side, the initial investment cost of a bicycle and other accessories can be an obstacle for those who cannot afford them (Daley et al., 2007; Félix et al., 2019; Shaaban, 2020; Blitz, 2021).

Impacts of topological factors and environmental issues on cycling preference are also investigated in the literature. Bad and extreme weather conditions, polluted air, and exhaust fumes can discourage people from cycling (Heinen et al., 2010; Götschi et al., 2016; Nahal and Mitra, 2018; Iwińska et al., 2018; Félix et al., 2019; Shaaban, 2020; Blitz, 2021). The topological factors, including the hilly structure of the region, have also been identified as a barrier in many studies (Daley et al., 2007; Heinen et al., 2010; van Bekkum et al., 2011; Félix et al., 2019; Rahman et al., 2022).

In the literature, questionnaires and interviews have been used to identify factors that affect citizens' cycling decisions. These methods offer strong policy recommendations by reflecting the views and expectations of different cyclist groups. However, the obstacles and motivators of cycling may change over time and traditional methods are insufficient to capture the temporal changes in the cyclists' perceptions. Adopting this perspective, in this study, a social media analytics approach was applied that can dynamically monitor the changes in perceived drivers and barriers over five years.

3. Methodology

In all modern data analysis processes, such as data mining, text mining, social media mining, and opinion mining, the primary data source is huge, and it is challenging to extract meaningful insights from it (Azzalini and Scarpa, 2012). There is no universally accepted structural analysis process for any mining method. The solution process and the steps involved may differ from case to case and analyst

to analyst (Sharda et al., 2020). Although specific necessary steps must be included in the process (such as data gathering and pre-processing), these steps may differ and reveal the unique structure of each study (Kumar et al., 2014). This differentiation is due to the source of the text data (social media, comments, academic articles, etc.) and the purpose of the analysis (topical modeling, summarizing, emotion extraction, etc.). In this study, a serialized text mining process was applied. Fig. 1 presents the main stages of this methodology.

The analysis process started with *data gathering*. It is crucial to obtain highly representative data at the data-gathering stage, which should have the ability to reflect the overall opinions of users. The source for this process, called corpus in text mining, can be derived from customer comments, academic articles, and social media content. In this study, user comments for biking were obtained from a social media platform, Twitter, because of its text-intensive structure, which also allows measuring the impact of each message on other users (i.e., retweets, quotes, likes). All tweets in the five years from November 2016 to November 2021 with the keyword "Bisiklet[1]" were collected by the web scraping method. The initial data were collected from Turkey and included 601,883 main text tweets and datetime, retweet, like, and quotes values for each tweet.

The second stage is the *data pre-processing*. This stage is vital for data analysis performance because errors to be made in this process are called "systematic errors" and negatively impact the analysis results (Sharda et al., 2020; Cebeci, 2020). At this stage, in addition to the classical text mining pre-processing steps, the content-specific tweets were cleaned and abbreviations and emojis were converted. A special list was created for the abbreviations and a Turkish version of a comprehensive dictionary was used for emoji conversion (Full Emoji List, 2021). After all pre-processing steps were completed, the number of pre-processed clean tweets was 442,368.

Although the data is cleaned after the data preprocessing process, it is still in text format. To digitize this text format, firstly, a numerical matrix form is prepared with *feature selection and extraction*, and then it is prioritized with the TF-IDF (Term Frequency-Inverse Document Frequency) method. In the TF-IDF method, the amount of information each word carries (the importance of the word) is obtained by evaluating its frequency in the document and the total corpus altogether (Aizawa, 2003). The output of this step is the term-document matrix, which also includes TF-IDF values.

Corpora that are the subject of text mining are often related to more than one topic in a particular field. The thematic evaluation can be made by assigning each corpus document to the subtopics. This process can increase the generalization ability of the findings. To carry out the thematic evaluation, it is necessary to determine which document is related (or not related) to topics. This process that expresses each document's coding to predetermined topics is called *topic modeling*.

The first step of the topic modeling is to determine the topics (barriers and drivers for biking). Many dimensions have been described in the literature that affect the cycling decision. These dimensions are discussed in Section 2. Based on the national and international literature review, seven barriers and seven drivers were determined and their sub-dimensions were defined (Table 1). These dimensions will be used in the following coding step. More comprehensive tables were provided in Appendices A and B, including the references for each topic.

The second step of topic modeling is the assignment (coding) of messages to relevant topics. Manual assignment of messages to relevant topics in a vast corpus can be time-consuming and error-prone. The supervised learning approaches were used for this process, where it is necessary to create a particular machine learning set (a pre-coded sample). In the first coding stage, a machine learning set was created and 5% of the data was read and coded, and 16,522 of them were assigned to at least one barrier or driver. In the next stage, a separate machine learning model was run for each class in order to increase the prediction performance, taking into account the multiplicity of output classes (7 barriers and 7 drivers). Table 2 presents the machine learning techniques with the highest performance.

Six different machine learning algorithms were applied for 14 topics, and the rest of the data was coded with these high-performance algorithms. Therefore, the topic modeling phase was completed. At the end of this stage, 248,566 tweets out of 442,368 were coded into at least one topic and sent to the information extraction stage. 141,878 of the tweets included in the calculation were posted by different users, and only 17 users created more than a hundred tweets. This shows that tweets are not dominated by a narrow user group and research data has a high representativeness of the sample.

A sentiment analysis approach was used to assess social media users' opinions for each tweet at the *information extraction* stage. Sentiment analysis (also known as opinion mining, idea analysis, idea extraction, emotion mining, subjectivity analysis, effect analysis, review mining) is used to analyze the polarity (positive or negative) of a text containing emotion written by users with natural language processing or dictionary-based approaches (Poria et al., 2018; Liu, 2020).

Understanding human emotions and behaviors have always attracted academics' and practitioners' attention (Golder et al., 2020). Although natural language processing studies started in the 1950s (Yue et al., 2019), researchers have tended to sentiment analysis with increased access to opinionated documents since the early 2000s (Pozzi et al., 2017; Yue et al., 2019; Liu, 2020). The TurkishBERT algorithm, the Turkish version of the BERT (Bidirectional Encoder Representations from Transformers) model, was used in this study. BERT is a deep learning-based natural language processing approach and synthesizes the relationship by analyzing sentences from right to left and from left to right. It uses the transformer model, a feedforward neural network variant, for transformation (learning). BERT can acceptably process large amounts of data in parallel with its highly functional architecture (Devlin et al., 2018).

The term-document matrix (containing only frequencies) was used as the main data source in this process. In addition, parameters such as retweets, quotes, and likes, which indicate the social spread effect of the messages were also derived with structural approaches.

[1] Bicycle in Turkish.

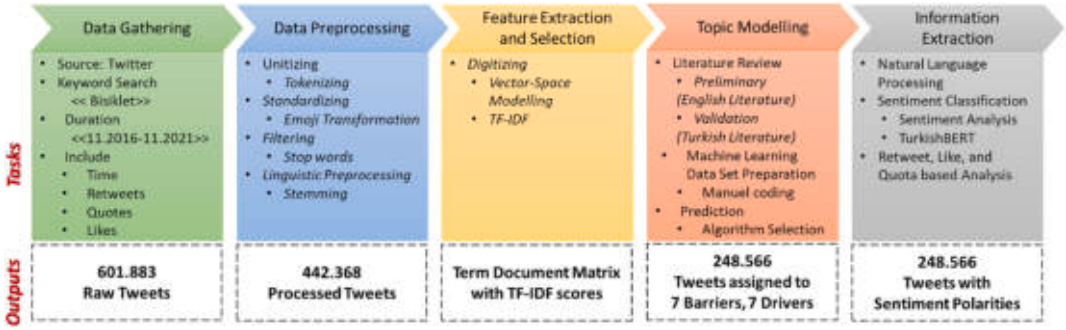

Fig. 1. Text mining process of the study.

Table 1
Topics for barriers and drivers.

Barriers	Sub-dimensions	Drivers	Sub-dimensions
Physical infrastructure	✓ Bike lane conditions ✓ Lack of parking/refreshment facilities ✓ Limited bike paths/connections ✓ Insufficient lighting ✓ Manmade terrain and poor road surfaces ✓ Signalization ✓ Lack of integration with public transport	Physical infrastructure	✓ Direct cycling routes ✓ Safe parking/refreshment facilities ✓ Bike network information ✓ Bike lane network and connections ✓ Improved/safer intersections ✓ Lighting ✓ Connection to public transport
Topological	✓ Hilly roads ✓ Unattractive surroundings	Health	✓ Weight control ✓ Physical activity and sport
Safety & security	✓ Intersection safety ✓ Aggressive driving ✓ Pedestrians ✓ Bike theft ✓ Attitude towards cyclists ✓ Disrespectful motorists ✓ Traffic jam ✓ Cycling in traffic	Practicality	✓ Ease of transport ✓ Rapidity ✓ Flexibility ✓ Poor public transport
Personal	✓ Familiarity with bike routes ✓ Time/distance to destination ✓ Distance from work ✓ Carrying belongings ✓ Time is taken to cycle ✓ Physical effort involved ✓ Health problems ✓ Lack of cycling skills ✓ Arrive sweat ✓ Lack of time ✓ Not confident in cycling skills	Fun & Challenge	✓ Entertainment ✓ Self-competition ✓ Experiencing the challenge ✓ Getting away and resting
Social	✓ Parental consent ✓ Social status ✓ Gender issues (harassment against women) ✓ Lack of cycling culture ✓ Lack of cycling network	Social	✓ Need for socialization ✓ Social image ✓ Appreciation and recognition ✓ Biking culture in society (friends and family members) ✓ Social support ✓ Positive social norm
Economical	✓ Cost of clothing and bike ✓ Economical conditions	Cost efficiency	✓ Low-cost transport mode ✓ High costs of private cars ✓ Affordable cost of biking
Environmental	✓ Bad weather conditions ✓ Polluted air ✓ Exhaust fumes	Environmental awareness	✓ Ecological sensitivity and awareness

Table 2
Prediction performances of machine learning algorithms in learning sets.

	Barriers	Learning Algorithms	Accuracy*	Recall*	Precision*	F1*
Barriers	Physical infrastructure	Histogram-Based Gradient Boosting Classification Tree	0.9333	0.9475	0.9167	0.9318
	Topological	Bagging Classifier	0.9797	1.00	0.9594	0.9793
	Safety & security	Bagging Classifier	0.9561	0.9465	0.9637	0.9550
	Personal	Bagging Classifier	0.9573	0.9608	0.9554	0.9581
	Social	Gradient Boosting	0.9343	0.9433	0.9268	0.9349
	Economical	AdaBoost Classifier	0.8952	0.9032	0.8889	0.8960
	Environmental	Bagging Classifier	0.9394	0.9556	0.9271	0.9412
Drivers	Physical infrastructure	Gradient Boosting	0.9569	0.9534	0.9583	0.9558
	Health	Histogram-based Gradient Boosting Classification Tree	0.9162	0.9342	0.9030	0.9183
	Social	Gradient Boosting	0.9351	0.9302	0.9346	0.9324
	Fun & challenge	Bagging Classifier	0.9429	0.9476	0.9402	0.9439
	Practicality	Bagging Classifier	0.9056	0.9134	0.8958	0.9045
	Cost efficiency	Extra-Trees	0.9202	0.9221	0.9124	0.9167
	Environmental awareness	Soft Voting/Majority Rule Classifier	0.9362	0.9345	0.9398	0.9371

* *Accuracy* refers to the ratio of correctly predicted observation to the total observation. *Precision* is the ratio of correctly predicted positive observations to all positives. *Recall (Sensitivity)* is the ratio of correctly predicted positive observation to all correctly predicted observations (positive or negative). *F1* refers to the weighted average of recall and precision.

4. Findings

4.1. Distribution of tweets

The number of tweets about cycling has increased very rapidly over the years. The number was 2405 in 2016 and 86,260 in 2021 (Fig. 2). Considering that the number of Twitter users in Turkey increased only by 5% in the same period (dogruveri.com, 2016; Günyol, 2021), it is obvious that the increase is mostly due to the interest in cycling. Tweets about drivers and barriers have increased in parallel, and drivers received more tweets than the barriers.

Table 3 shows what percentage of tweets referred to the relevant dimension. For instance, 4% of tweets referred to topological factors. Note that the sum of the values in the table is more than 100%. This is because each tweet could be assigned more than one topic due to the multi-labeling approach. Topics that accept more tweets were the subject of more social media posts and were more discussed among users. Therefore, it can be assumed that the ratios given in the table show the importance of each dimension for the citizens. Values in Table 3 are visualized with a green-red color scale. The color scale from green to red indicates increasing barriers (green refers to the weaker barrier and red refers to the stronger barrier) and decreasing drivers (green refers to the stronger driver and red refers to the weaker driver). Thus, green is more desirable for both barriers and drivers.

The most-tweeted barrier is economical (29%), which refers to bicycle, equipment, and clothing costs, budget constraint, expensive bike brands and types, exorbitant price increases, and the exchange rate of the dollar/euro against the Turkish Lira. The proportion of tweets with these contents reflecting the economic issues increased during the observation period. This finding indicates that economical barriers are the most discussed topic on social media. It is followed by physical infrastructure. Overall, 22% of tweets about barriers are related to physical infrastructure. Interestingly, the proportion of tweets related to this topic has decreased over the years. There were similar tweets about safety&security and social barriers, 19% and 18%, respectively. Safety&security tweets have not changed significantly over the years, that is, the subject has always maintained its importance. However, messages regarding social issues have been increasing in recent years, meaning they have been the subject of more discussion. Environmental and personal topics are less discussed (15% and 11%, respectively), while topological issues are the least (4%). This may be because cyclists do not see topological factors as a barrier. In fact, previous studies in Turkey have shown that topological factors are not a significant obstacle,

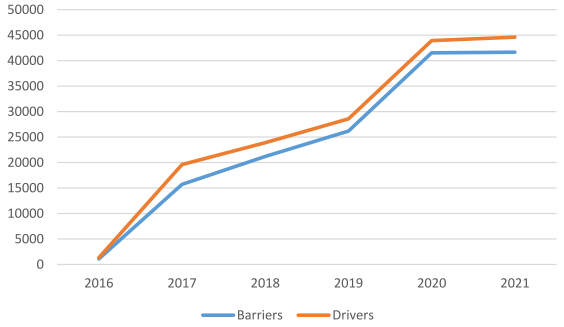

Fig. 2. Number of tweets.

Table 3
The proportion of each dimension.

	Dimensions	2016	2017	2018	2019	2020	2021	Overall
Barriers	Physical infrastructure	28%	25%	20%	24%	24%	19%	22%
	Topological	3%	3%	4%	4%	3%	3%	4%
	Safety & Security	19%	17%	18%	18%	20%	18%	19%
	Personal	7%	9%	11%	10%	12%	12%	11%
	Social	10%	16%	19%	19%	16%	18%	18%
	Economical	26%	27%	29%	26%	28%	31%	29%
	Environmental	20%	16%	15%	15%	14%	14%	15%
Drivers	Physical infrastructure	6%	6%	6%	8%	9%	7%	7%
	Health	53%	56%	48%	46%	46%	49%	48%
	Social	9%	9%	11%	10%	10%	10%	10%
	Fun & Challenge	8%	11%	12%	12%	11%	12%	12%
	Practicality	12%	10%	12%	13%	12%	10%	11%
	Cost efficiency	19%	17%	22%	21%	22%	25%	22%
	Environmental Awareness	18%	15%	19%	19%	17%	17%	18%

except for the regions where geographic conditions were harsh (Yıldız and Bektaş, 2021).

On the other side, health is the most important motivator and almost half of the messages are related to health. This is followed by cost efficiency (22%). Similar to the economical dimension, tweets about cost efficiency have increased in recent years. The increase in fuel costs in Turkey and the rise in automobile prices more than bicycles have made the bicycle an economical transport alternative. Cyclists have also highly emphasized environmental awareness in their social media sharing (18%). Fun&challenge, practicality, and social motivators were mentioned in similar proportions (12%, 11%, and 10%, respectively), while the physical infrastructure was the least discussed topic (7%).

4.2. Sentiment analysis

Citizens' satisfaction will be interpreted based on the sentiment results of each dimension. The average sentiment scores are presented in Fig. 3. Here, downward graphs indicate negative sentiments (lower satisfaction) while upward graphs indicate positive sentiments (higher satisfaction). As can be seen, the average sentiment values of the barriers and drivers are clearly differentiated, and, as expected, drivers received higher average sentiment values, that is, higher satisfaction. This evidence that machine learning algorithms produced robust results.

Table 4 shows what percentage of tweets about each variable contain positive (green gradient) and negative (red gradient) statements. For example, 77% of safety&security related tweets contain negative statements (sad face), while only 23% have positive content (happy face). Please note that the sum of the positive and negative sentiment ratios equals 100%. Overall, negative sentiments are higher than positives. This is expected because users are more likely to post negative comments on social media platforms

Fig. 3. Sentiment trends towards overall barriers and drivers.

Table 4
Sentiment analysis results.

		2016		2017		2018		2019		2020		2021		Overall	
		☹	☺	☹	☺	☹	☺	☹	☺	☹	☺	☹	☺	☹	☺
Barriers	Physical infrastructure	68%	32%	67%	33%	71%	29%	73%	27%	76%	24%	75%	25%	73%	27%
	Topological	66%	34%	64%	36%	59%	41%	66%	34%	69%	31%	66%	34%	65%	35%
	Safety & Security	70%	30%	78%	22%	77%	23%	76%	24%	76%	24%	77%	23%	77%	23%
	Personal	61%	39%	62%	38%	64%	36%	63%	37%	66%	34%	64%	36%	64%	36%
	Social	68%	32%	53%	47%	56%	44%	59%	41%	65%	35%	57%	43%	59%	41%
	Economical	67%	33%	66%	34%	67%	33%	68%	32%	72%	28%	71%	29%	70%	30%
	Environmental	66%	34%	65%	35%	67%	33%	68%	32%	69%	31%	65%	35%	67%	33%
Drivers	Physical infrastructure	69%	31%	61%	39%	67%	33%	69%	31%	74%	26%	69%	31%	70%	30%
	Health	44%	56%	45%	55%	49%	51%	51%	49%	55%	45%	52%	48%	51%	49%
	Social	67%	33%	45%	55%	56%	44%	57%	43%	59%	41%	50%	50%	54%	46%
	Fun & Challenge	50%	50%	49%	51%	53%	47%	54%	46%	60%	40%	58%	42%	56%	44%
	Practicality	57%	43%	65%	35%	67%	33%	70%	30%	74%	26%	73%	27%	71%	29%
	Cost efficiency	64%	36%	59%	41%	63%	37%	66%	34%	69%	31%	65%	35%	65%	35%
	Environmental awareness	59%	41%	52%	48%	58%	42%	60%	40%	65%	35%	59%	41%	60%	40%

(Whatman, 2018), particularly on public transit issues (Collins et al., 2013; Schweitzer, 2014; Yang and Anwar, 2016; Haghighi et al., 2018; El-Diraby et al., 2019). In Turkey, for example, approximately 7 million tweets were sent daily in 2021, and only 41% contained positive comments (Oypan, 2021).

The dimension with the highest dissatisfaction among barriers is safety&security (77%). There has been an increasing negative slope over the years, indicating growing concerns about safety and security issues. This is followed by physical infrastructure with a rising negative slope (73%). Economical conditions received the third-highest negative sentiment score (70%). The contraction in the Turkish economy, the depreciation of the Turkish Lira, and the increase in bicycle and equipment prices may have caused this situation. Environmental, topological, and personal factors received similar negative rates, while social barriers were the least dissatisfied.

Health received the greatest satisfaction on the driver's side (49%). This is followed by the need for socialization, fun & challenge, and environmental awareness (46%, 44%, and 40%, respectively). This result shows that the bicycle is used for health, socialization, and entertainment purposes rather than as a means of transportation in Turkey. Indeed, such a great dissatisfaction with the cost efficiency, physical environment, and practicality is an indicator of this.

Some important results were obtained when the change in the sentiment scores between 2016 and 2021 was examined (Figs. 4 and 5). Downward red graphs indicate negative sentiments (dissatisfaction) while upward green graphs indicate positive sentiments

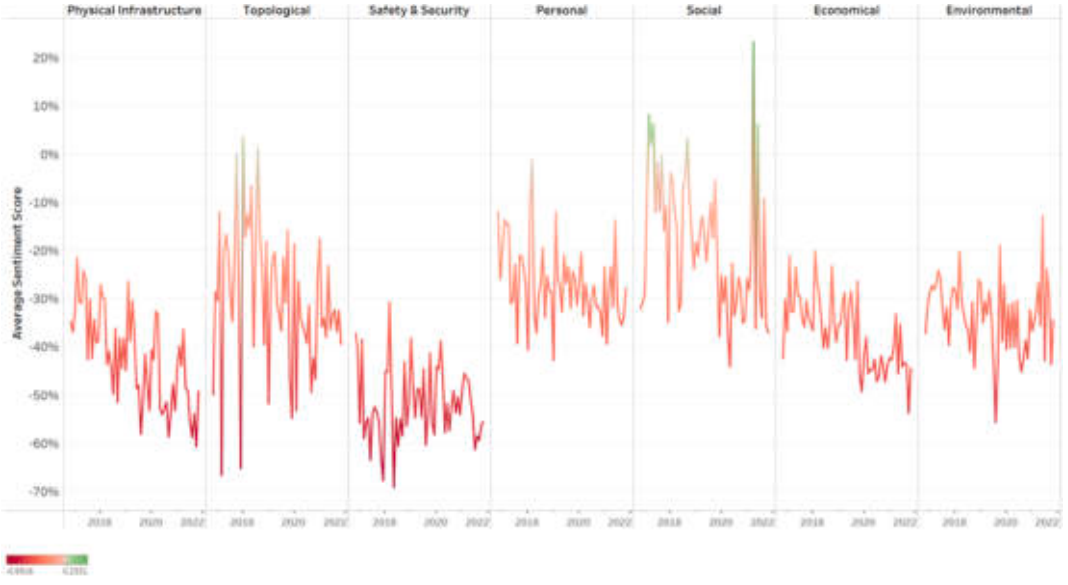

Fig. 4. Sentiment trends toward barriers.

(satisfaction). Positive sentiments on both barriers and drivers reflect the satisfaction of citizens, while negative sentiments are the opposite. Undoubtedly, the most striking result emerged in the social dimension. Indeed, the level of satisfaction in the social dimension has increased rapidly on both the barrier and driver. This shows that negative social perceptions have been less prevalent, cycling has gained social acceptance and has been adopted as a socialization tool. On the other hand, dissatisfaction with the physical infrastructure barriers increased rapidly. In addition, the average sentiment values of safety&security, economical, fun&challenge, health, and practicality decreased significantly during the observation period. The recent increase in satisfaction with cost efficiency can be explained by the sudden increase in automobile prices, as the bicycle has begun to be seen as a lower-cost means of transportation. Some interesting findings have also been obtained in the Covid-19 pandemic. All positive sentiments decreased in 2020 when the pandemic was most intense. In post-pandemic 2021, increases were recorded in all positive sentiments.

4.3. Social impacts of dimensions

To measure the social spread effect of the messages, the number of retweets, likes, and quotes received by the tweets were listed (Table 5). Topics that receive more retweets, likes, and quotes can be considered to cause more social interaction among users. Table 5 indicates decreasing social impact from green to red color scale, that is, green refers to stronger social impact while red refers to weaker social impact. In general, drivers seem to create more interaction than barriers. In other words, social media messages related to enablers received more retweets, likes, and quotes than those in barriers. Environmental awareness has the most impact among the drivers. Tweets about this dimension received an average of 4.49 retweets, 26.73 likes, and 0.28 quotes. This is followed by physical, social, and cost efficiency dimensions. The lowest effect was created by health. This finding is surprising because it is the most attractive dimension with the most messages and the highest positive sentiment.

Among the barriers, social and safety&security dimensions created the most interaction. Social topics received the most retweets and likes, and safety&security received the most quotes. This finding shows that social media users react more to social issues and security problems. Economical, environmental, personal, and physical infrastructure cause less impact, while topologic issues received the lowest retweet, like, and quotes.

5. Discussion

Surveys and interviews are widely used in the literature to explore the enablers and barriers of cycling. This study adopted social media analytics supported by topic modeling, machine learning, and sentiment analysis. Despite the methodological difference, the findings of this research are largely consistent with the literature, demonstrating that social media analytics has produced consistent results with traditional methods.

The literature has widely emphasized that health (Götschi et al., 2016; Manaugh et al., 2017; Iwińska et al., 2018; Sabyrbekov and Overland, 2020) and physical infrastructure (Daley et al., 2007; Handy et al., 2010; Iwińska et al., 2018; Félix et al., 2019; Blitz, 2021) are the most important drivers of cycling. In line with the literature, our study found that health is the most discussed topic in social media with the highest level of satisfaction, while physical infrastructure is the second. The literature has also argued the importance of the socio-cultural factors in the adoption and maintenance of cycling (Daley et al., 2007; Cole et al., 2010; Heinen et al., 2010; Bonham and Wilson, 2012; Willis et al., 2015). The height of positive sentiments of social factors supports this claim. Another similarity is related to safety&security where many studies have identified this as a significant obstacle (Daley et al., 2007; Dill and Voros, 2007; Götschi et al., 2016; Manaugh et al., 2017; Hopkins and Mandic, 2017; Iwińska et al., 2018; Sabyrbekov and Overland 2020; Blitz,

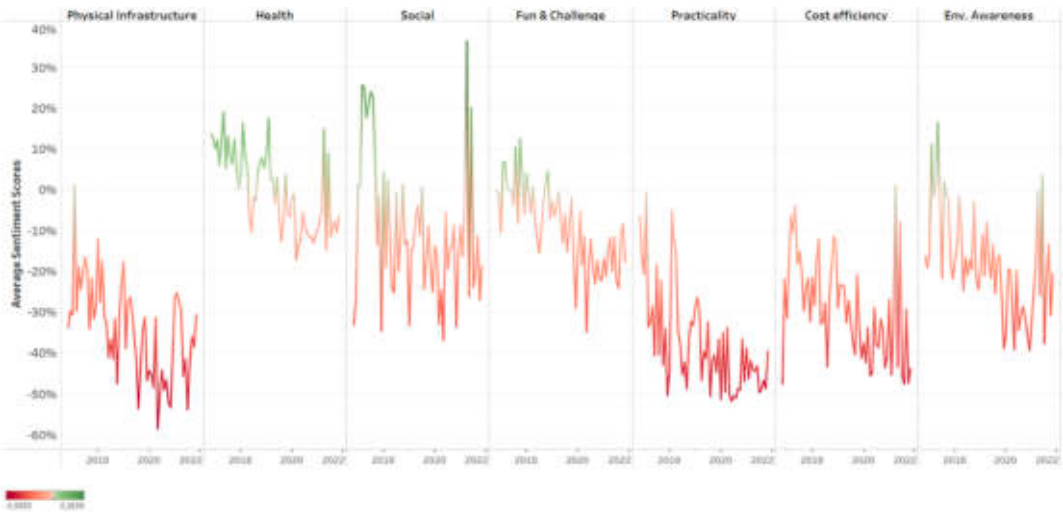

Fig. 5. Sentiment trends toward drivers.

Table 5
Average impacts.

	Retweet	Like	Quote
Physical infrastructure	1.30	11.41	0.14
Topological	1.00	9.13	0.09
Safety & Security	1.79	12.95	0.21
Personal	1.35	13.96	0.11
Social	2.82	18.35	0.18
Economical	1.67	12.55	0.13
Environmental	1.28	13.13	0.12
Overall Barriers	1.70	13.54	0.15
Physical infrastructure	2.77	20.95	0.19
Health	1.62	10.92	0.10
Social	3.35	17.55	0.19
Fun & Challenge	2.50	15.48	0.15
Practicality	1.80	12.36	0.16
Cost efficiency	2.68	15.51	0.18
Environmental awareness	4.49	26.72	0.28
Overall Drivers	2.16	13.87	0.15

2021). Our results indicated that the highest dissatisfaction among all barriers was related to safety&security.

In addition to these similarities, findings specific to Turkey were also revealed. The cycling experience varies according to the topological, cultural, economical, and social structure of the region where the study is conducted. For instance, weather conditions have been identified as a significant barrier as it is very snowy and icy in Poland (Iwińska et al., 2018) and very hot in Qatar (Shaaban, 2020). However, we found that the weather conditions are not a critical obstacle for Turkey. The most striking result was observed in economical issues. Economical factors have not been taken into account in many studies, or its effect on cycling was found to be negligible (Félix et al., 2019; van Bekkum et al., 2011). However, in this study, the economic costs of cycling have been the most discussed topic on social media. In line with the general economic conjuncture of the country, the rate of economic issues in social media posts has increased over the years, and the level of satisfaction has decreased regularly. Another finding unique to Turkey is related to the practicality dimension. Many studies in the literature have revealed that practicality is an essential enabler of cycling (Handy et al., 2010; Heinen et al., 2011; Fishman et al., 2012; Wang et al., 2015; Iwińska et al., 2018). However, our findings have shown that this is not true for Turkey. Indeed, the practicality dimension has the highest dissatisfaction rate among drivers.

Social media analytics have also provided important insights into the temporal variation of determinants of cycling, which is missing in traditional methods. The method presents a dynamic view reflecting the last five years instead of taking a snapshot, which potentially creates more comprehensive insights into the impacts of implemented policies and shifts in attitudes and cultural values. Some important temporal findings are as follows. Despite the increasing investments in recent years, dissatisfaction with the infrastructure is growing, showing that these investments are not managed properly and cannot respond to user demands. As a matter of fact, cycling is losing its feature of being a practical mode of transport with each passing year. The increase in security anxiety is also very noticeable. Compared to the first year of observation, dissatisfaction with safety has increased significantly, which suggests that investments in infrastructure do not improve cyclist safety. Also, positive feelings about social issues increased significantly during the observation period, demonstrating that biking has begun to gain social acceptance and has been adopted as a socialization tool.

6. Conclusion and suggestions

Many government-supported projects have been implemented and infrastructure investments have been made to encourage biking in Turkey. This study applied social media analytics to identify the barriers and encouraging motivators for cycling from the citizens' perspective and recommend policy suggestions to promote biking. The research data covers the period from 2016 to 2021 and more than 600,000 Twitter messages were analyzed with topic modeling, machine learning, and sentiment analysis.

Results showed that the proposed method produced compatible results with surveys and interviews, and is a reliable method to capture cyclists' perceptions. This finding supports Casas and Delmelle (2017), who concluded that social media analytics and unstructured data source can be used as a complement to traditional methods. The method also allowed us to reach more participants from a wider geographic region, monitor the temporal changes in their perceptions, and provide a dynamic view of policymaking.

The main findings and suggestions are as follows. The most emphasized topic in social media is the economical barrier (including the cost of bikes and equipment, price increases, exchange rates, budget constraints, etc.) and its rate has increased over the years. The negative sentiments of users also increased in the same period. During the research period, the increase in bicycle and equipment prices may have caused this result. Considering the increased number of comments and the low satisfaction rate, it is clear that economic issues are one of the biggest obstacles to cycling. It is important to note that social media posts reflect users' perceptions of barriers and

drivers rather than their actual behavioral responses. The excessive increase in bicycle and equipment prices due to the deterioration of the economy in recent years may have caused users to reflect their price sensitivities on social media. The government's reduction of taxes on bicycle imports, incentives for production, and abolishing the excise tax can break this perception and make bicycle prices more affordable.

Another critical factor is the physical infrastructure. An excellent physical infrastructure can be an important motivator, while an inadequate infrastructure would be perceived as an obstacle. Although significant investments have been made in the bicycle infrastructure in recent years, negative perceptions have increased. Previous studies in Turkey have also revealed physical infrastructure to be the most important barrier (Balcı et al., 2018; Karagöz and Erdem, 2019). This shows that investments in recent years were not managed properly and could not motivate citizens to cycle. Further studies are needed to guide infrastructure investments by identifying the sources of infrastructural problems, e.g. bike lane conditions, connections, lack of parking/refreshment facilities, and signalization.

Safety&security is the dimension with the highest rate of negative sentiment. Compared to the first year of the research period, negative comments have increased significantly. This indicates that security concerns are gaining importance among cyclists and infrastructure investments in recent years have failed to improve cyclist safety. Indeed, studies conducted in different provinces of Turkey have shown that safety concerns are very high among cyclists (Kalaycı et al., 2015; Karagöz and Erdem, 2019). Since most of the problems in this dimension are caused by aggressive driving, disrespectful motorists, pedestrians using the bicycle path, and attitudes toward cyclists, campaigns promoting and adopting a cycling culture can be beneficial to overcome safety issues.

Among the drivers, health, social, fun&challenge, and environmental awareness received the highest rates of positive statements, respectively. This finding shows that citizens are aware of the positive externalities of biking. Practicality and cost efficiency have lower satisfaction rates, demonstrating that bicycles are used for sports and entertainment rather than transportation. The regular decrease in practicality satisfaction supports this finding. This finding strongly supports previous studies in Turkey, which reveal that bike is used for sports, health, and entertainment rather than as a means of transportation (Koçak, 2016; Öztürk and Çoruh, 2019; Yıldız and Bektaş, 2021). Thus, it is recommended that policies to promote cycling should focus on urban cycling infrastructure opportunities that would facilitate commuting to work and school.

The socio-cultural dimension also provided important predictions for cycling habits. As a barrier, the negative sentiment rate of social factors (parental consent, social status, gender issues, lack of cycling culture, and cycling network) has decreased over the years and it received the lowest value. As a driver, the level of satisfaction (need for socialization, social image, appreciation, recognition, biking culture in society, social support, positive social norm) increased significantly compared to the first period and received the second-highest rate. Moreover, citizens reacted more to tweets about social issues by retweeting, liking, and quoting, emphasizing the general interest. This critical finding evidenced that the negative perspective on cycling has started to change and it has become a socialization tool by being adopted by society. These findings and suggestions can guide policy decisions to promote biking in Turkey.

In addition to practical contributions, this study allowed the proposed new method to be compared with traditional ones (surveys and interviews). The research findings are generally compatible with previous studies in which traditional methods were applied. Nevertheless, social media analytics has advantages and disadvantages compared to conventional methods. The first advantage lies in the scope of the research population. Social media analytics can reach a much larger population more quickly and easily and provides more comprehensive analysis using big data. Moreover, unlike the traditional methods, it allows observing the change of user comments over time and offers a more dynamic evaluation perspective. Voluntary messages left on social media can also provide more robust inputs for analysis.

On the other hand, the most important disadvantage of the proposed approach is that it offers an unstructured analysis environment. Questionnaires and interviews can explain the differences between the needs and expectations of users according to the purpose of cycling, gender, age, cyclist type, and frequency of use by providing more structured analysis (Daley et al., 2007; Manaugh et al., 2017; Iwińska et al., 2018; Shaaban, 2020; Doran et al., 2021; Blitz, 2021). Instead, social media analysis offers general considerations and struggles to explain subgroup-specific differences (Rathore and Ilavarasan, 2016). In addition, the like-oriented nature of social media can push users to make manipulative and extreme comments (Whatman, 2018). Also, social media analytics requires more sophisticated techniques and hardware infrastructure for data collection, extraction, and analysis, and these processes take a long time when the data set grows.

Finally, the limitations of the study and suggestions for future studies will be presented. In this study, we focused on the main barrier and driver dimensions and the individual effects of sub-dimensions on cycling were not considered. In future studies, more specific and practical results can be obtained by focusing on the sub-dimensions of each dimension. Also, emotion analysis can be used in future studies to provide additional insights into how citizens actually feel about perceived drivers and barriers, such as anger, fear, and happiness.

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Appendix A. Barriers for Biking

Dimensions	Physical infrastructure	Topological	Safety & Security	Personal	Social	Economical	Environmental	Method
Blitz (2021)	✓		✓			✓	✓	Questionnaire
Shaaban (2020)	✓	✓	✓	✓	✓	✓	✓	Questionnaire
Sabyrbekov and Overland (2020)	✓		✓				✓	Questionnaire
Félix et al., 2019		✓	✓	✓	✓	✓	✓	Questionnaire
Iwińska et al. (2018)	✓		✓	✓			✓	Questionnaire and interviews
Winters et al. (2015)			✓					Questionnaire and interviews
Clayton and Musselwhite (2013)	✓		✓	✓				Focus group and interview
Nkurunziza et al. (2012)	✓	✓	✓	✓	✓		✓	Questionnaire
van Bekkum et al. (2011)	✓	✓	✓	✓			✓	Questionnaire
Daley et al. (2007)		✓		✓	✓	✓	✓	Focus group
Öztürk and Gündüz (2020)	✓		✓					Questionnaire
Balcı et al. (2018)	✓				✓			Questionnaire
Çeyiz and Koçak (2015)	✓		✓		✓		✓	Interviews
Lorasokkay and Ağırdır (2011)	✓		✓				✓	Questionnaire

Appendix B. Drivers for Biking

Dimensions	Physical infrastructure	Health	Social	Fun & Challenge	Practicality	Cost efficiency	Environmental Awareness	Method
Félix et al. (2020)	✓							Pen&paper observation method
Shaaban (2020)	✓							Questionnaire
Sabyrbekov and Overland (2020)		✓	✓		✓			Questionnaire
Piatkowski et al. (2019)	✓							Questionnaire and interviews
Iwińska et al. (2018)	✓	✓	✓		✓	✓	✓	Questionnaire and interviews
Winters et al. (2015)	✓		✓					Questionnaire and interviews
Clayton and Musselwhite (2013)	✓			✓				Focus group and interview
Nkurunziza et al. (2012)	✓							Questionnaire
Heinen et al. (2011)		✓	✓	✓	✓	✓	✓	Questionnaire
Daley et al. (2007)		✓						Focus group
Yıldız and Bektaş (2021)		✓	✓	✓				Interviews
Kalaycı et al. (2015)		✓		✓			✓	Questionnaire
Çeyiz and Koçak (2015)		✓	✓	✓	✓			Interviews
Ardahan and Mert (2014)		✓	✓	✓	✓		✓	Questionnaire

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